



The First Spaceborne Observation of an Earth-Reflected GPS Signal

Stephen T. Lowe

John Labrecque

Cinzia Zuffada

Larry Romans

Larry Young

George Hajj

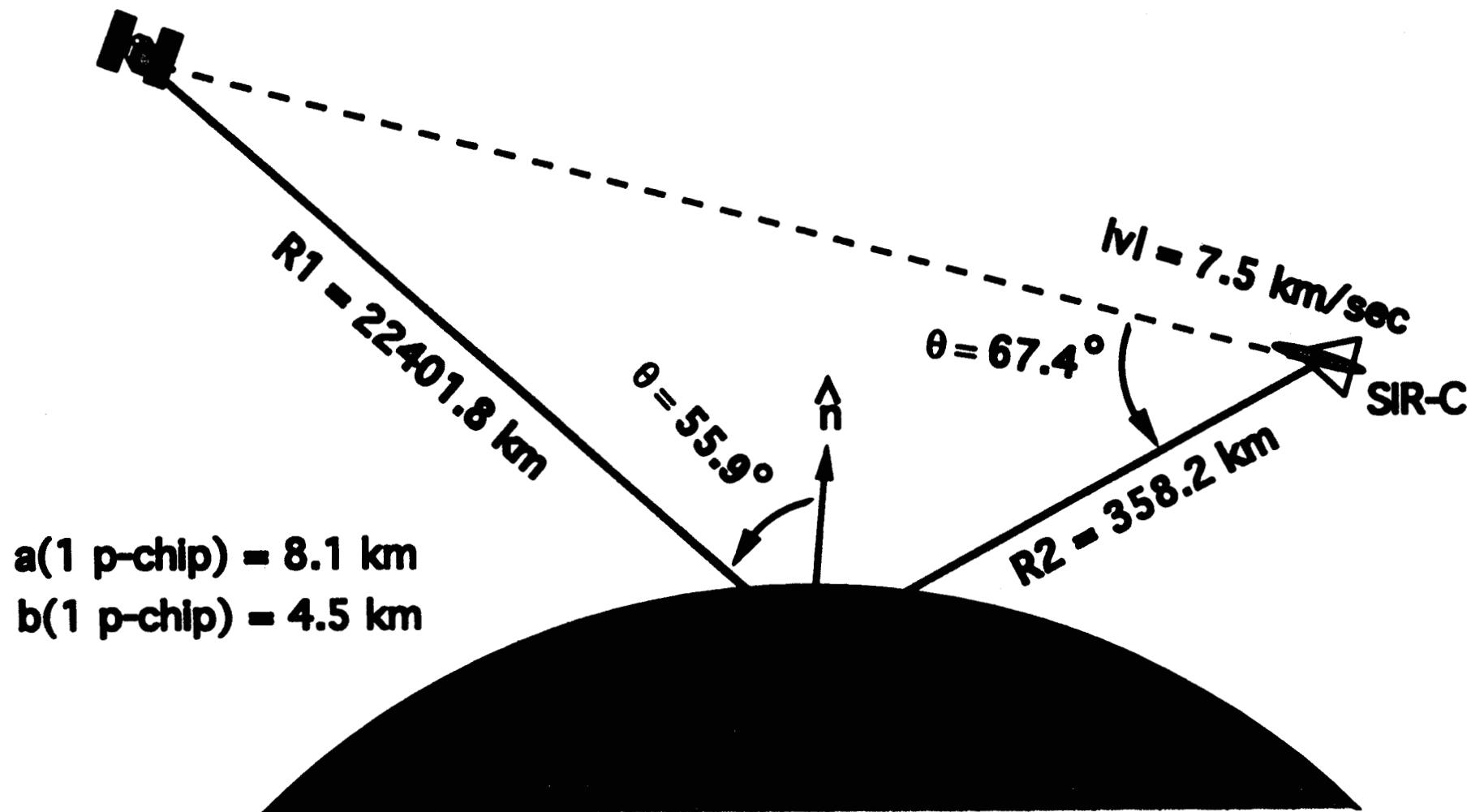
Jet Propulsion Laboratory,
California Institute of Technology

Submitted to JGR 1-24-00
steve.lowe@jpl.nasa.gov



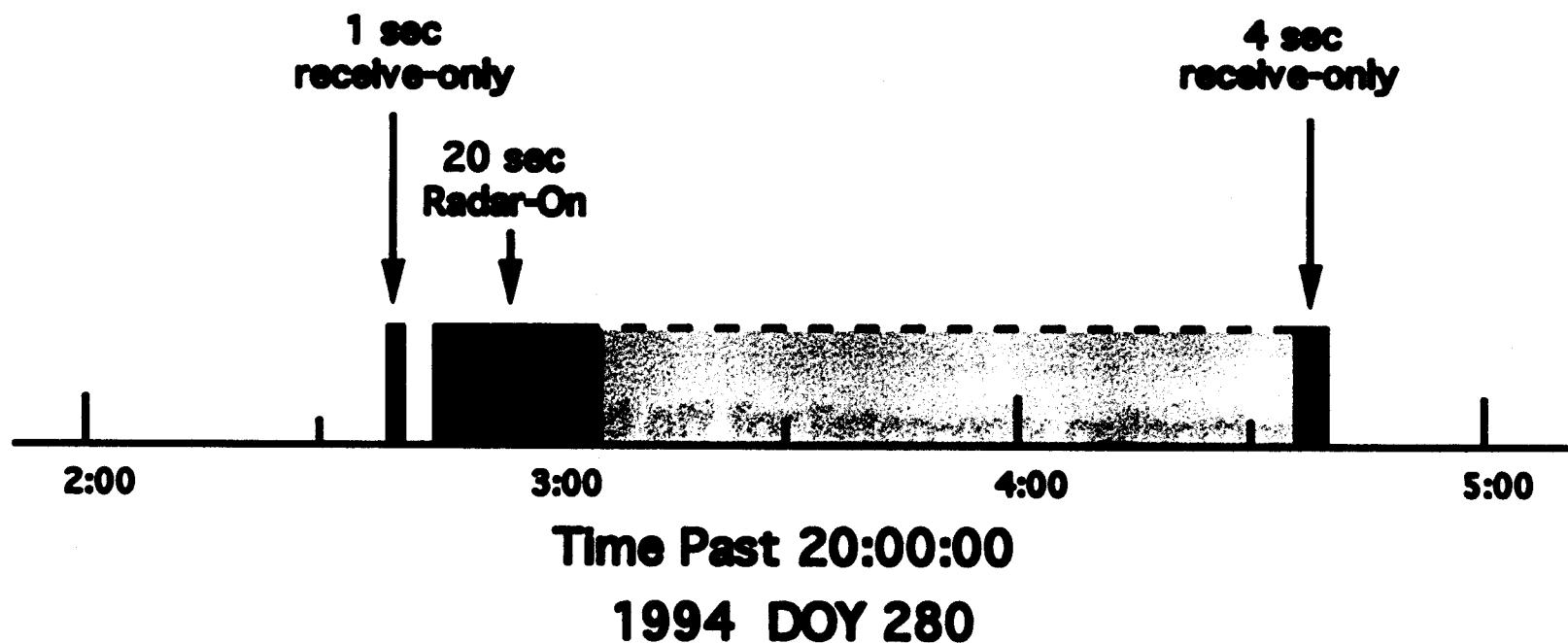
GPS
PRN 9

1994 DOY 280 20:04:35





Data Set

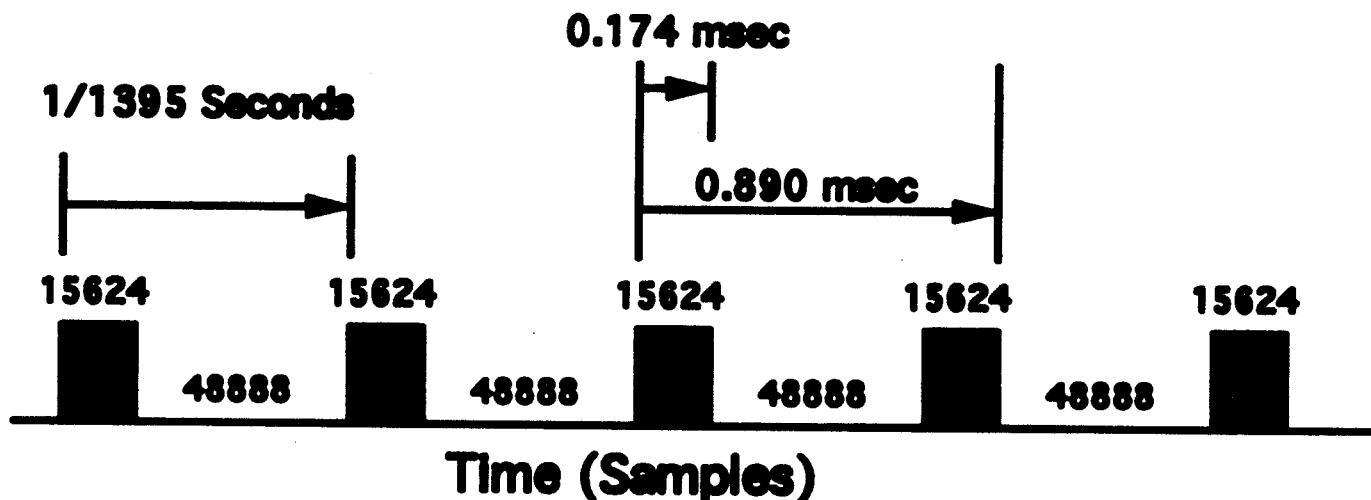


Data Set: Shuttle Radar Laboratory-2 Data

- High Resolution Mode
 - 89.99424 MHz sample rate
 - 1-byte samples
 - 40 MHz bandpass LSB
 - LO frequency = 14 x sample rate
= 1259.91936 MHz
- Radar turned off for listen-only calibration
 - 4 seconds of data (1-sec piece bad)
- Other Relevant Features
 - vertical polarization
 - 24% duty cycle



Sample Rate = 89.99424 MHz

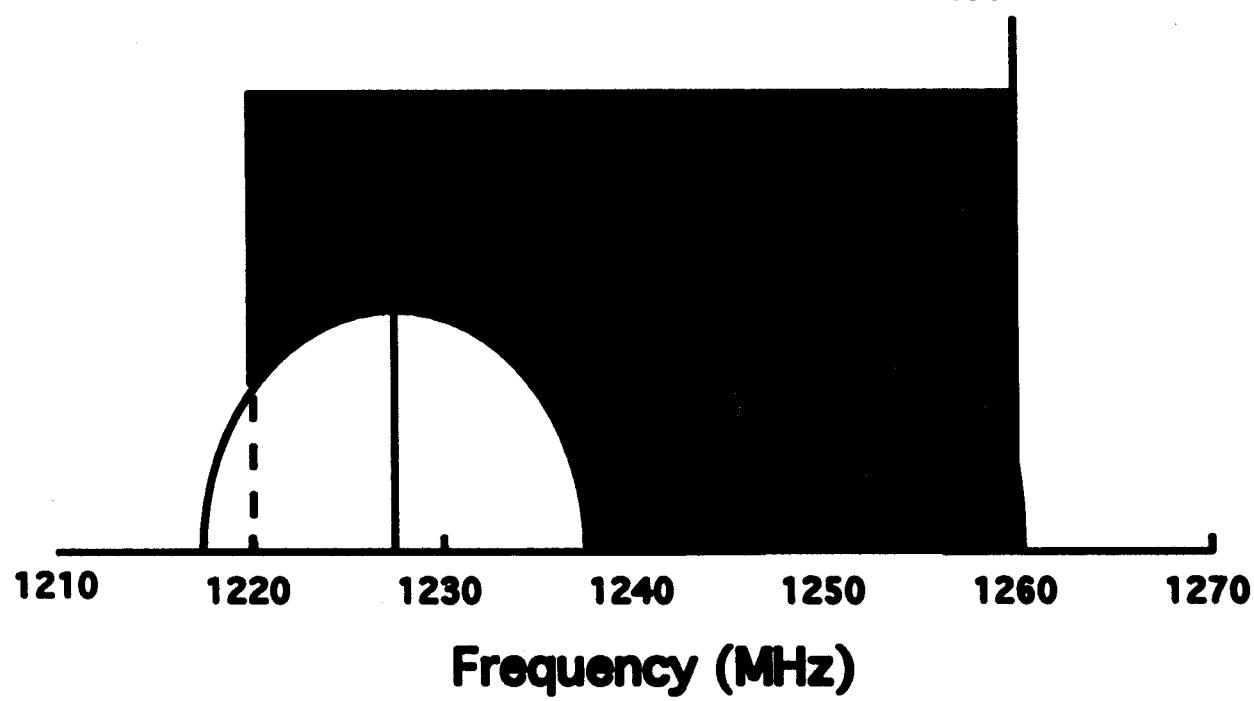


- 1395 data "lines" per second
- 15624 samples per line
- 27.9 lines per GPS data bit (0.02 sec)

JPL



1259.92





Signal Detection

- Searched for direct signal
 - Three model parameters
 - Clock error
 - Clock-rate error
 - Residual frequency error
 - Single 0.01 second coherent integration
 - Repeated for next 0.01 second (Data bits)
 - Used FFTs to speed program
 - Calculated 8388608 lags/iteration
 - 5 weeks CPU time (this attempt)
- After ~30 billion lags: Found Signal!

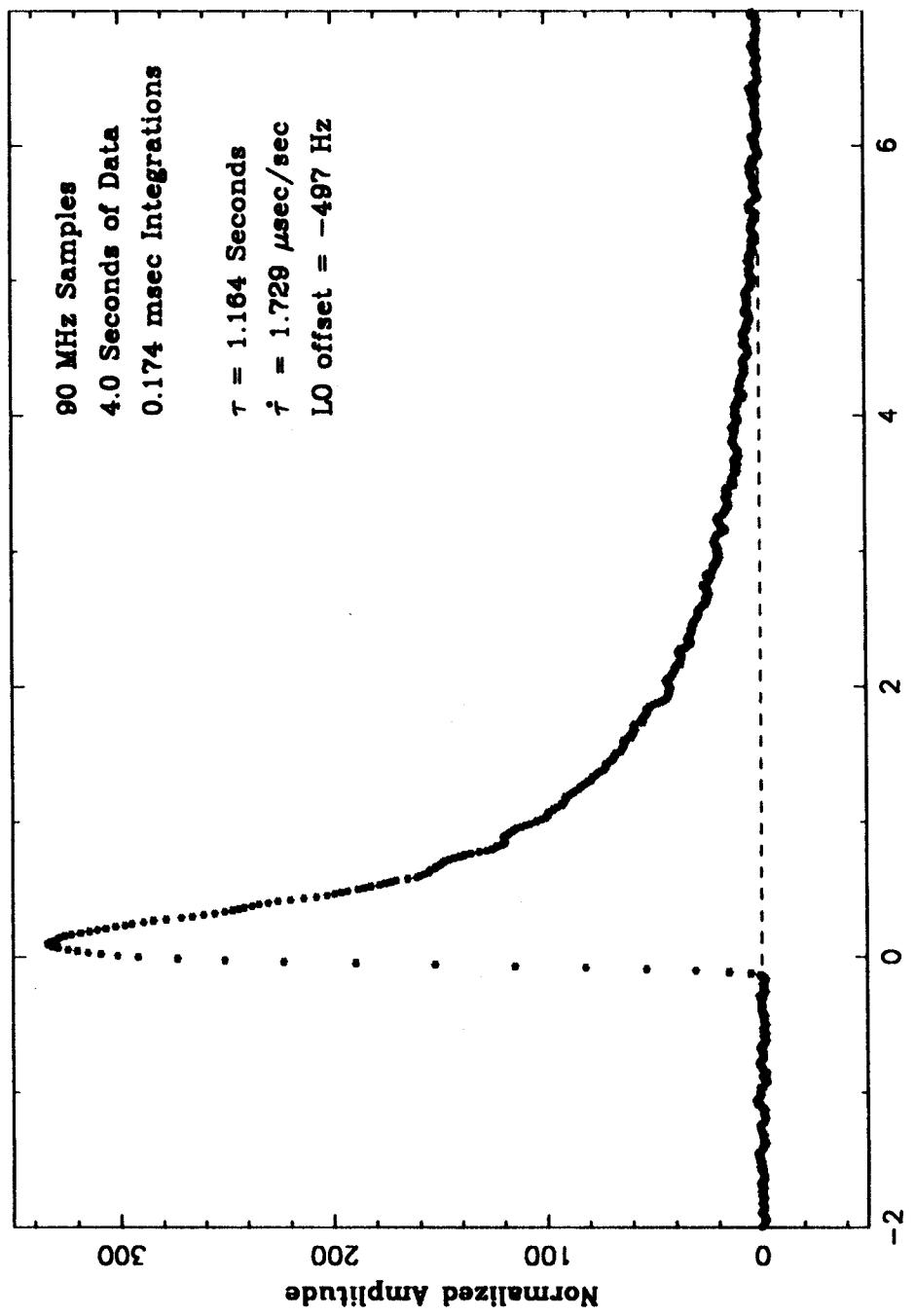


Figure 4

Time (Microseconds)



Signal Detection (cont)

- Model parameters far from those expected
 - Model clock error = 1.164 seconds
 - Model clock-rate error = 1.729 usec/sec
 - Model frequency error = -497 Hz
- Later found clock characteristics worse than expected
 - Explains the 2 clock parameter values
- Later added antenna gain pattern to analysis
 - Explains the LO offset almost exactly
- Evidence for reflected signal
 - Signal's temporal structure is as expected
 - Signal's coherence properties are as expected
 - Explains the LO offset almost exactly



Signal's Temporal Structure

- Create simulation of relevant effects:
 - Equi-delay annuli + auto-correlation function
 - Doppler filtering = $\text{sinc}(\text{integration time})$
 - Antenna gain pattern
 - Nonlinear SNR filtering effect
- Numerical integration of effects over fine grid on ocean
- Spirit of Zavorotny+Voronovich model

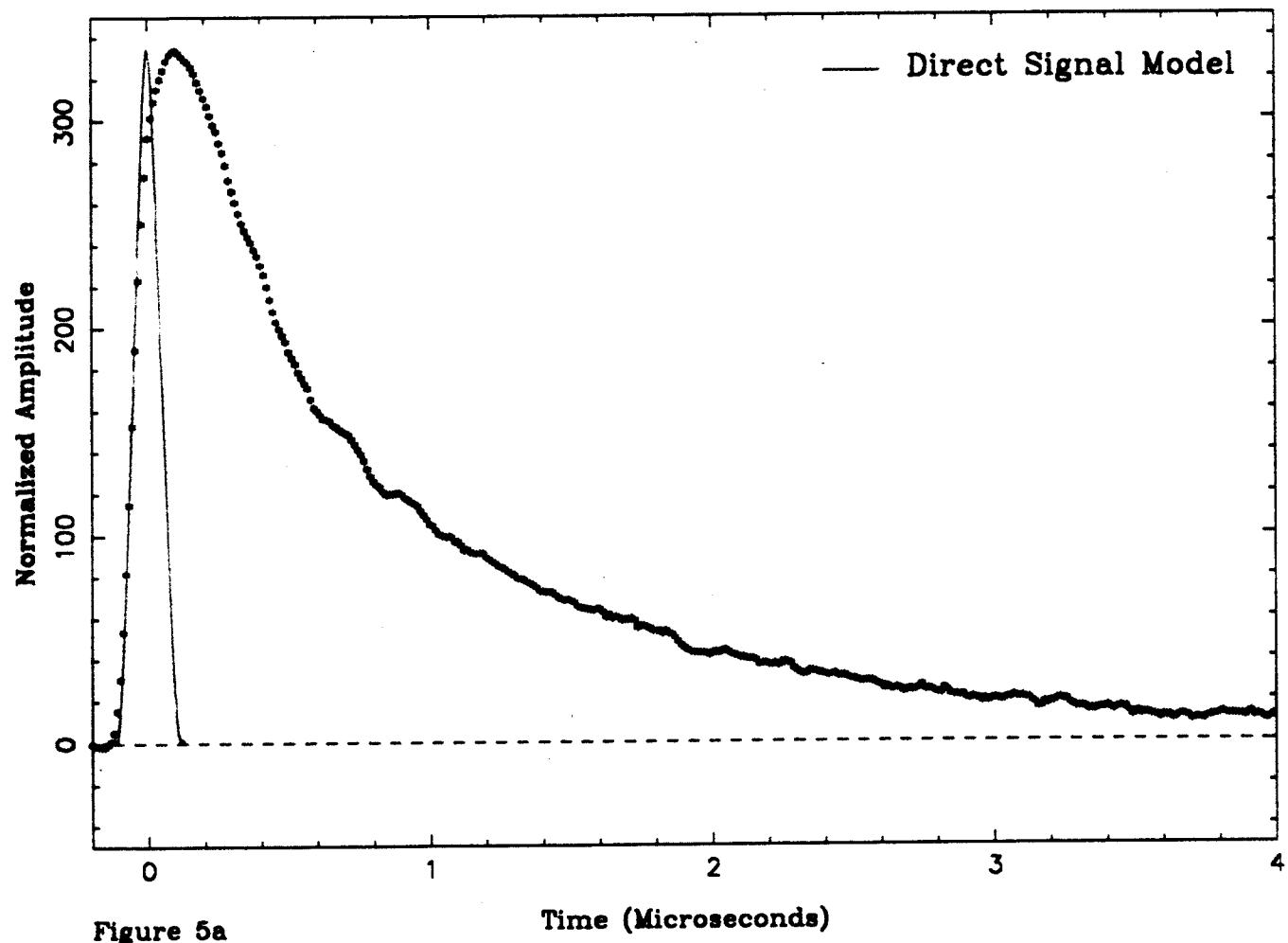
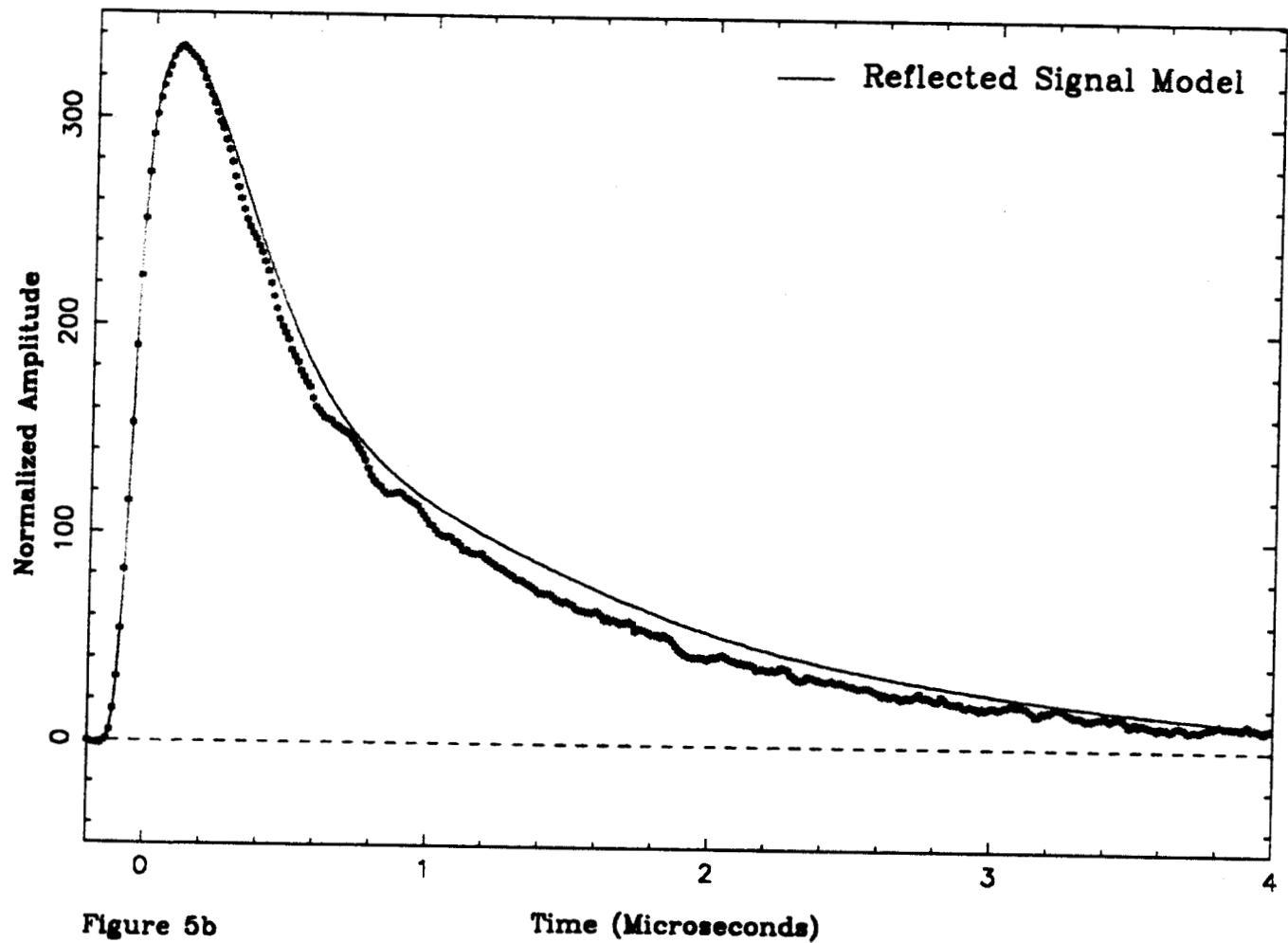
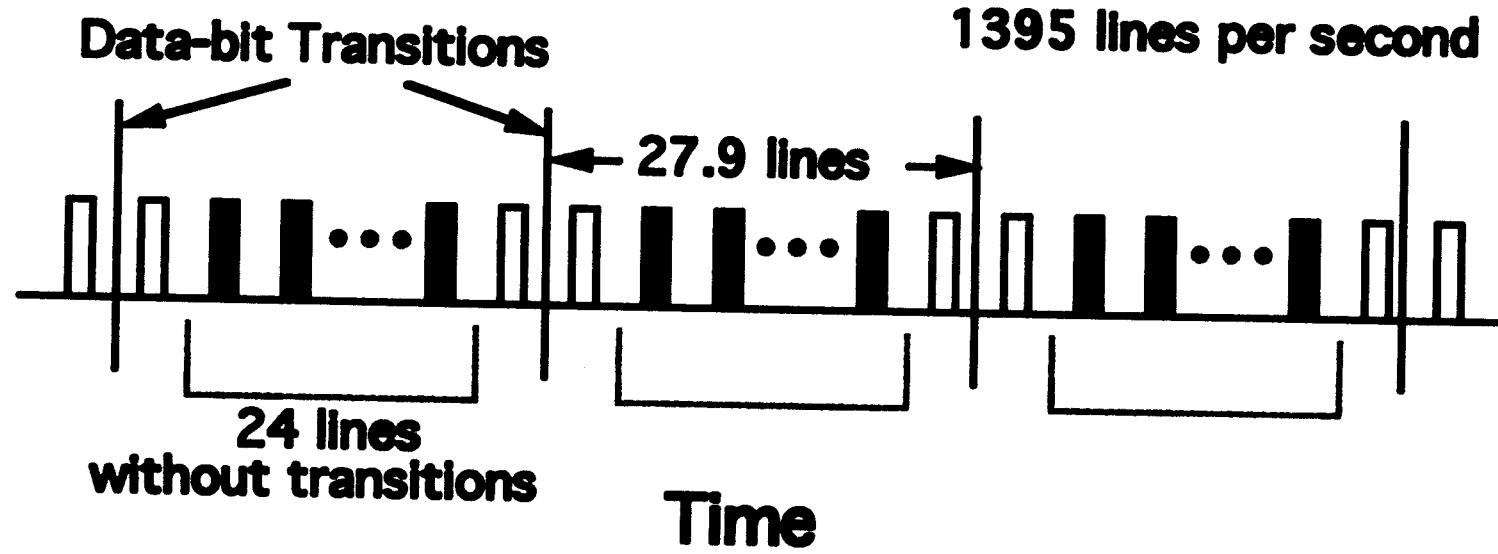


Figure 5a





Coherence-Time Measurement



- Choose 24 lines within data transitions
- Split into groups of 1, 2, 3, 4, 6, 12, 24 lines
(all possible divisors of 24)
- Sum all like groups

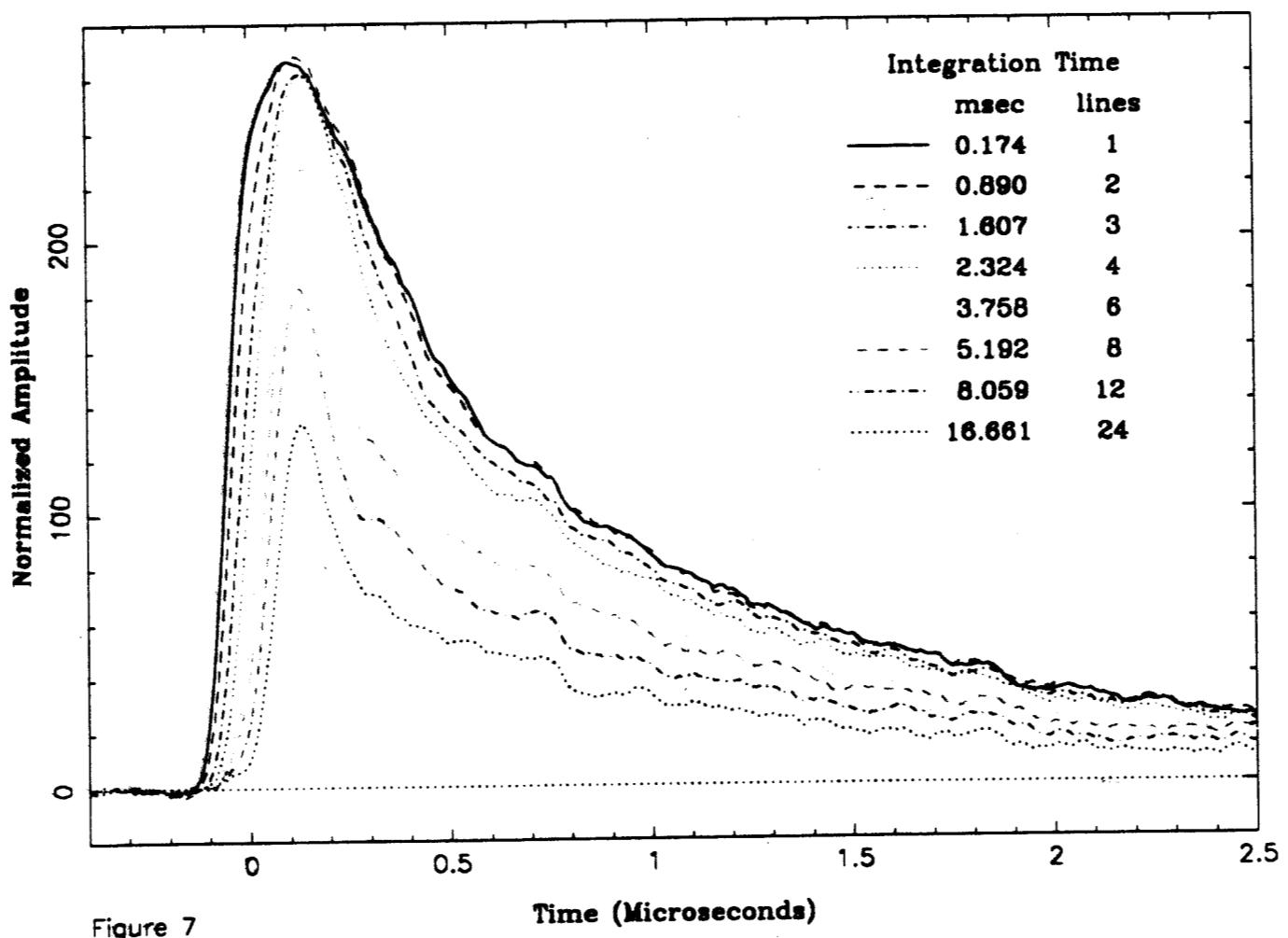


Figure 7

Coherence Time Measurement (cont)

- Must account for incoherent amplitude sums
- Must account for duty cycle and structure
 - Simulation!
- Generated 4-sec data trials
 - same duty cycle and structure as data
 - integrated using same method as data
 - included random-walk phase variable

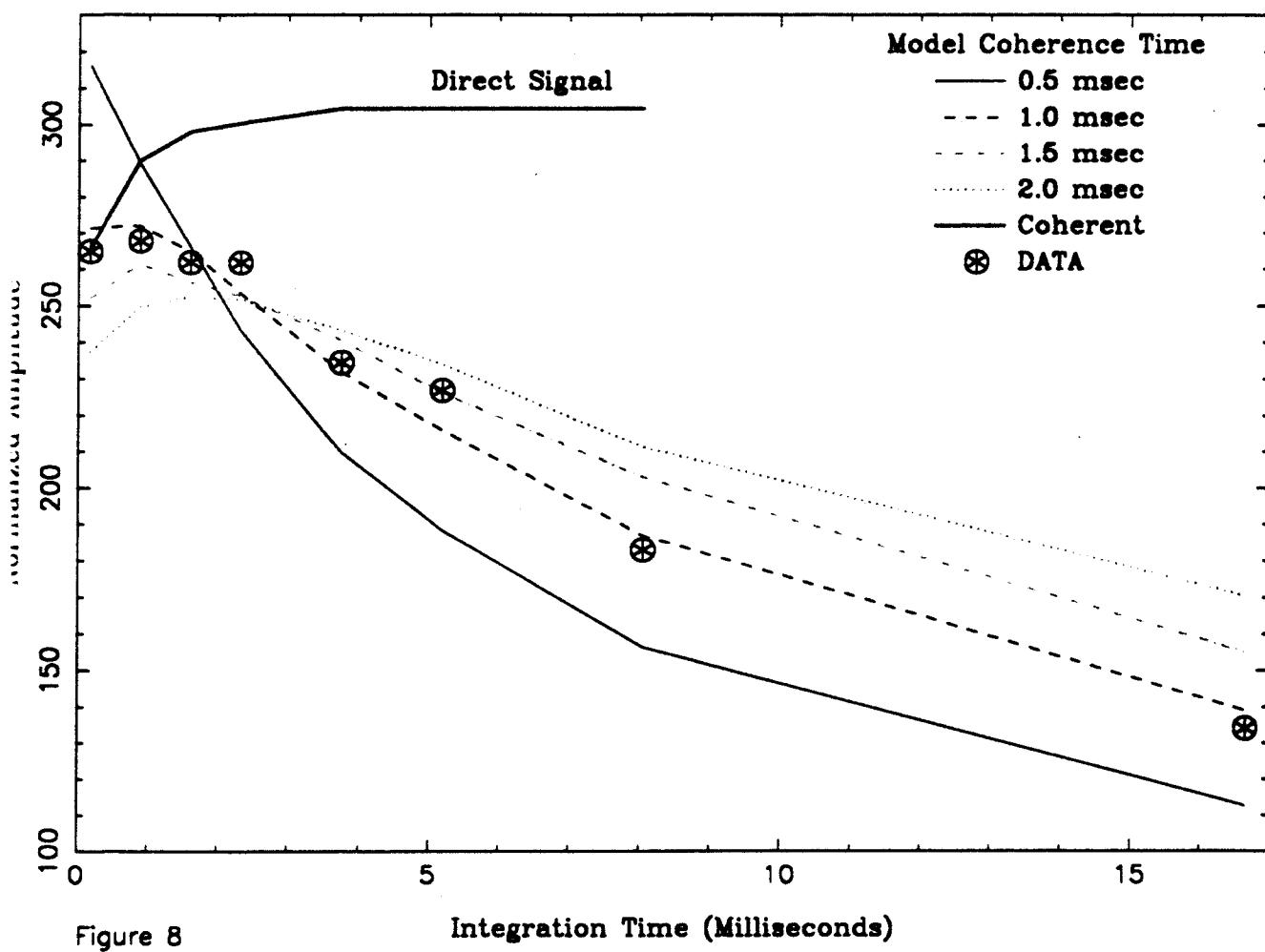


Figure 8

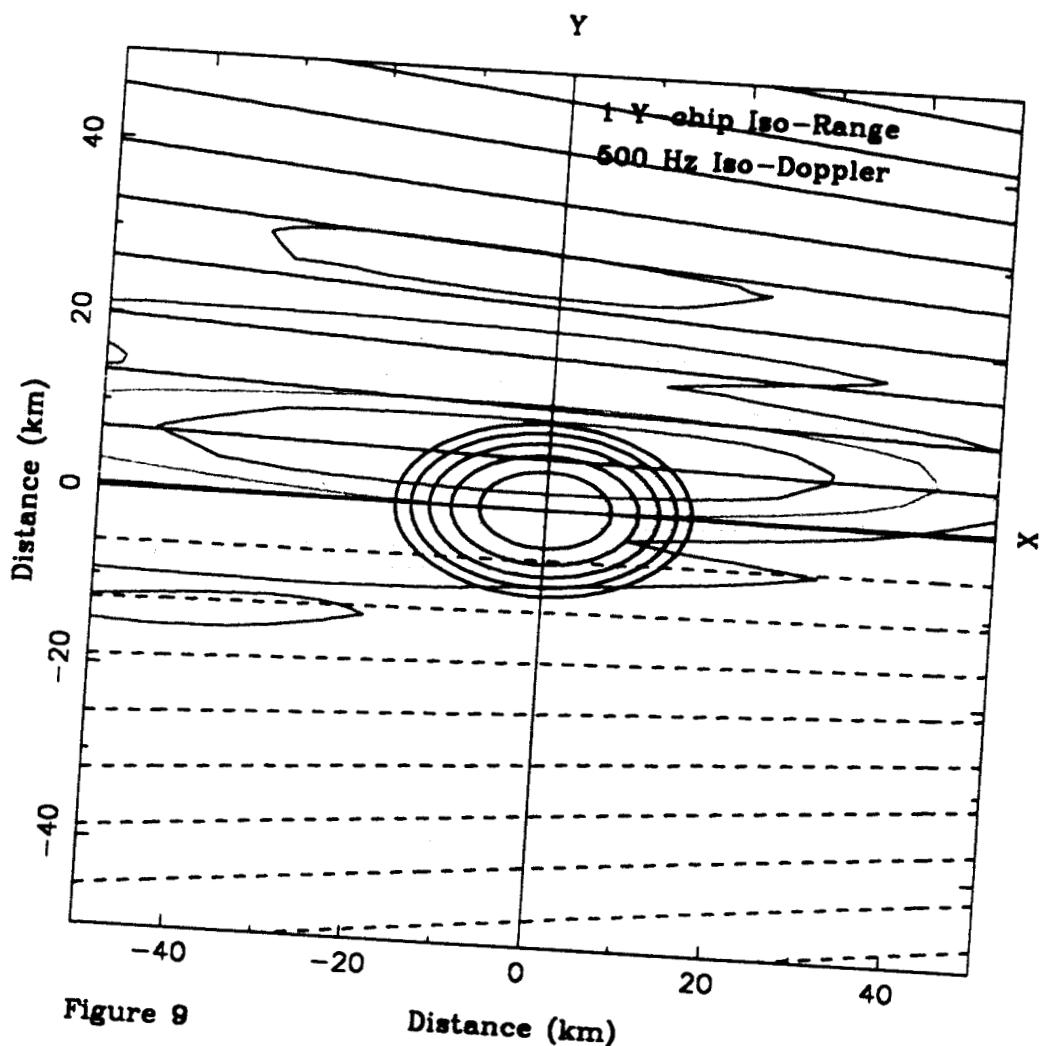


Figure 9



Summary

- **Detected reflected GPS signal from LEO receiver**
Signal shape, coherence properties: as expected
- **Scale to spaceborn altimetry missions**
Large, steerable aperatures required